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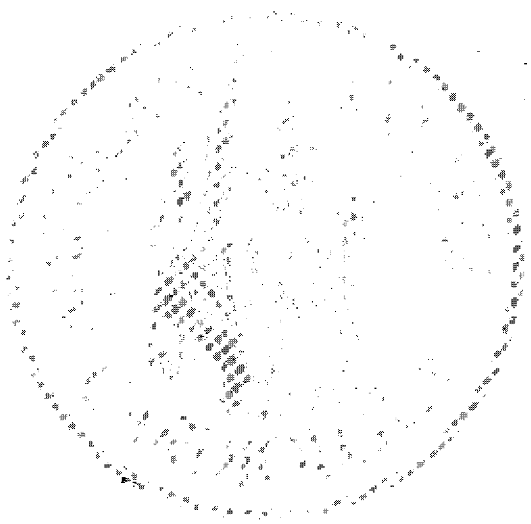

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Echocardiographic Visualization of Coronary Artery Anatomy in the Adult

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In the light of technologic advances and the development of new imaging planes, the feasibility of two-dimensional echocardiographic visualization of coronary artery anatomy was reevaluated in the adult. Thirty-five subjects were studied using an ultrasonograph equipped with a 3.5 and 5.0 MHz annular array transducer, digital processing and cine loop review. There were 18 normal subjects and 17 patients with heart disease, including 9 patients with valvular, 5 patients with coronary, 2 patients with congenital and 1 patient with cardiomyopathic disease. The mean age was 47 ± 18 years (range 17 to 79). Modifications of standard parasternal and apical views permitted high quality images of portions of each of the major epicardial vessels adequate for assessment of luminal diameter.

The left main coronary artery was seen in 30 (86%) of the 35 subjects and its bifurcation was seen in 15. The left anterior descending coronary artery was seen in 30 subjects (mean length 3.9 ± 2.3 cm, maximal length 7.5), the left circumflex artery in 11 (1.1 ± 1.0, maximal 3.0) and the right coronary artery in 32 (5.6 ± 2.6, maximal 12). Proximal and mid portions of the left anterior descending artery were seen in 23 and 11 subjects, respectively. The average proximal length visualized was 4.2 cm, and the average luminal diameter visualized was 4.9 mm. The average length of the mid left anterior descending coronary artery seen was 1.9 cm and the average luminal diameter seen was 4.6 mm. The proximal right coronary artery was seen in 17 subjects (average visualized length 2.7 cm and average diameter 3.1 mm). Portions of the mid right coronary artery were seen in 24 subjects (average length 3.6 cm and average diameter 3.1 mm). An average of 2.9 cm of the distal right coronary artery was seen in 18 subjects (average diameter 2.7 mm). Septal or diagonal branches were seen in 11 (31%) of the 35 subjects, a marginal branch in 1, the coronary sinus in all and smaller veins in 3. Coronary artery lesions were correctly identified in four of five subjects (two in the left anterior descending, one in the left main and one in the right coronary artery), but these were obscured in one subject by a calcified aortic valve.

Improved instrumentation combined with new imaging techniques permits extensive visualization of the adult coronary vasculature. The clinical utility of this technique for the noninvasive evaluation of coronary artery disease remains to be determined.

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The noninvasive delineation of coronary artery anatomy is of great importance yet has proved frustrating. To date, moderate success has been achieved with cross-sectional echocardiographic imaging of the left main coronary artery in adults (1-6), coronary aneurysms in children with mucocutaneous lymph node syndrome (Kawasaki disease) (7-10) and proximal coronary anatomy in young children with congenital heart disease (11,12). Problems inherent in the tomographic imaging of a curving vessel that changes position during the cardiac cycle, combined with technical difficulties including suboptimal resolution and penetration and limitations of image processing and display, have prevented adequate visualization of all but the most proximal or dilated coronary artery segments.

Recently, the introduction of commercially available annular phased array transducers, digital imaging processing and cine loop recall (13), combined with modification of standard image planes, has enabled visualization of coronary anatomy in the adult. The present study describes the cross-sectional echocardiographic methods employed and our results in an initial series of 35 patients.

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Methods

Study group. The study group consisted of 35 subjects, including 23 men and 12 women with an average age of 47 ± 18 years (range 17 to 79). Ten normal subjects and 5 patients with aortic regurgitation underwent echocardiographic imaging for the purpose of the study; the remaining 20 subjects were consenting volunteers recruited over a 4 day period from a total of 33 inpatients and outpatients having routine, clinically indicated echocardiograms. The diagnosis was coronary artery disease in five, ventricular septal defect in two and pulmonary stenosis, idiopathic cardiomyopathy, mitral stenosis, bacterial endocarditis and aortic stenosis in one patient each. No significant cardiac disease or isolated mitral valve prolapse was found in the remaining eight subjects. Cardiac diagnosis was confirmed by history, physical examination and full M-mode, two-dimensional and Doppler echocardiographic study. Cardiac catheterization or a thallium exercise test was required to confirm the absence of coronary artery disease in subjects >45 years old; angiography identified the location and severity of lesions in the five with coronary disease.

Coronary imaging. Coronary artery imaging was per-

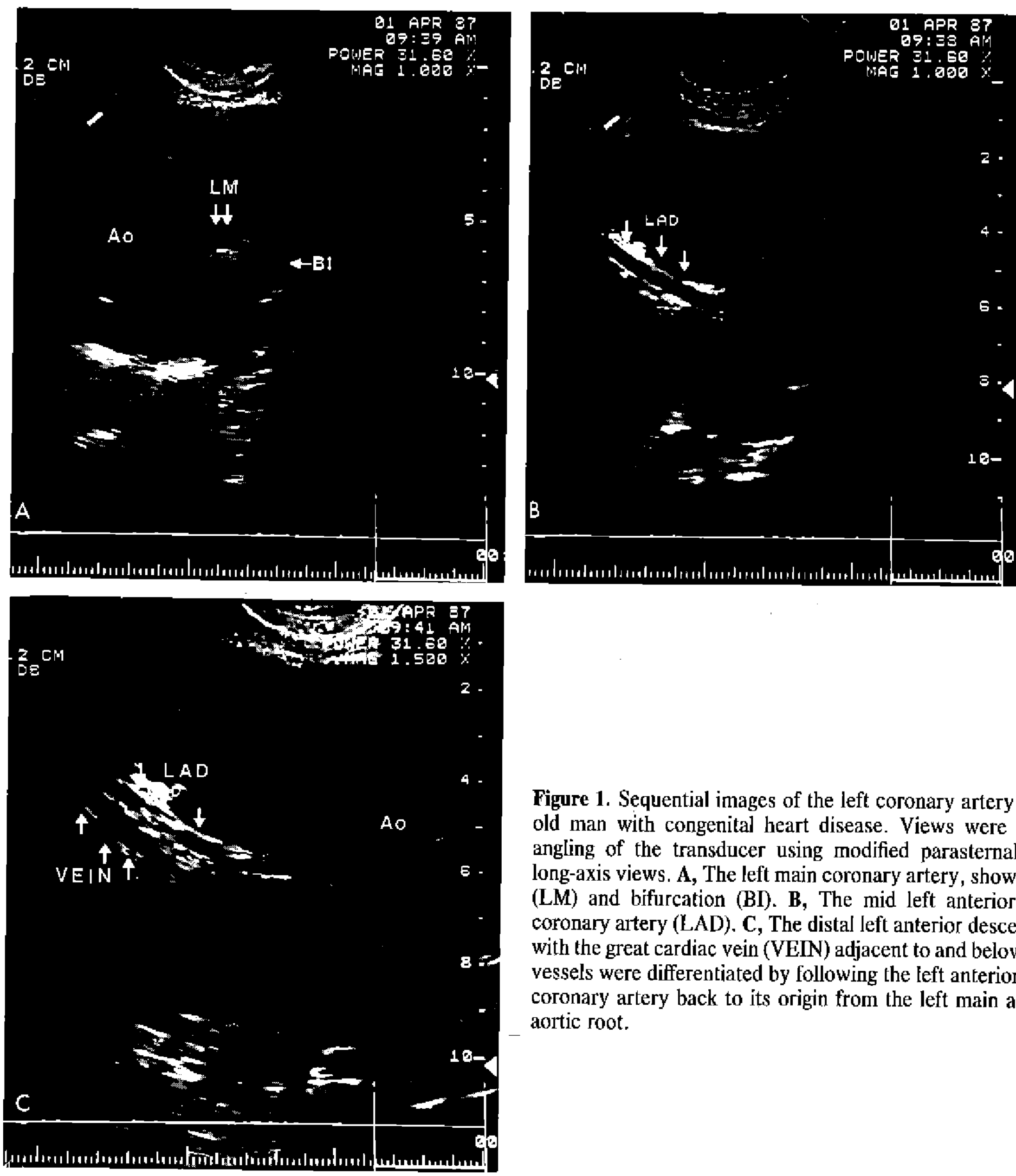
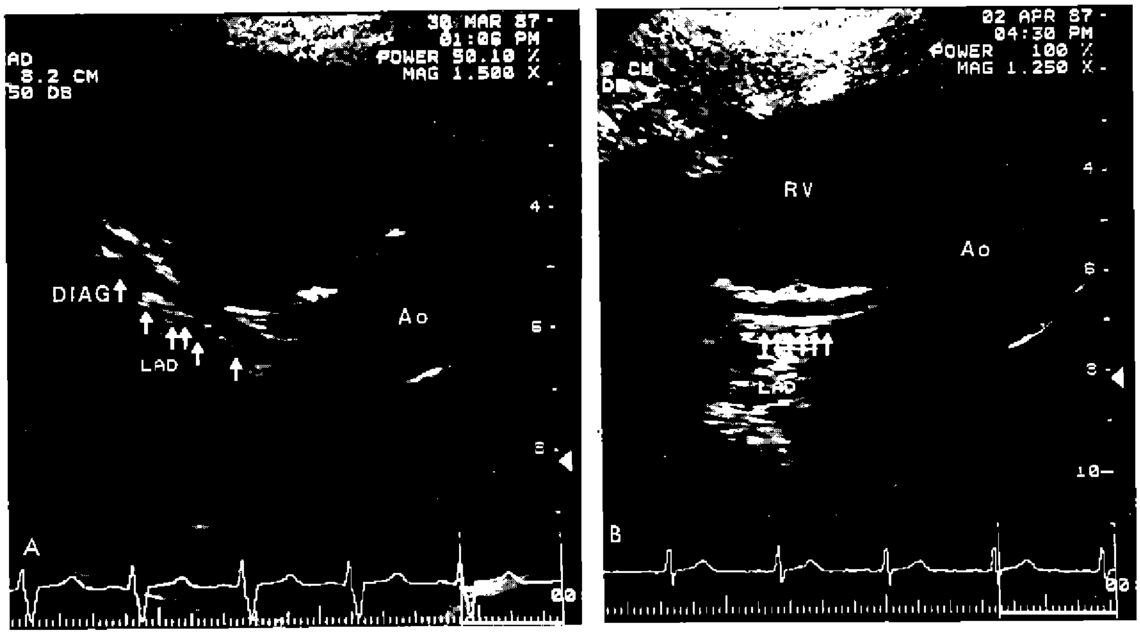


Figure 1. Sequential images of the left coronary artery in a 29 year old man with congenital heart disease. Views were obtained by angling of the transducer using modified parasternal short- and long-axis views. **A,** The left main coronary artery, showing its origin (LM) and bifurcation (BI). **B,** The mid left anterior descending coronary artery (LAD). **C,** The distal left anterior descending artery with the great cardiac vein (VEIN) adjacent to and below it. The two vessels were differentiated by following the left anterior descending coronary artery back to its origin from the left main artery. Ao = aortic root.



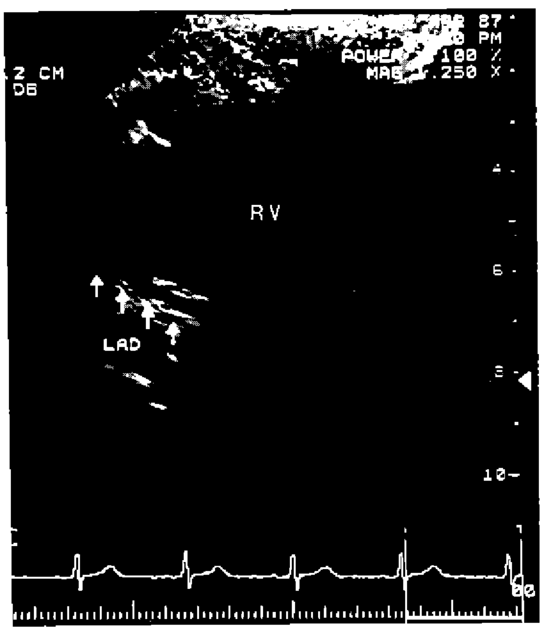


Figure 2. Imaging of the left anterior descending coronary artery (LAD). **A,** Proximal and mid portions showing diagonal branching (DIAG). The vessel courses from the left main artery and aortic root (Ao) at right in a curving arc toward the left and slightly anteriorly. The lumen of the diagonal (DIAG) branch is shown by the **most leftward arrow**. The image was obtained using a modified parasternal view in a 17 year old woman with congenital heart disease. **B** and **C,** Sequential images of the proximal (B) and mid (C) portions of the left anterior descending coronary artery were obtained by angling the transducer in a modified parasternal long-axis view. The images were obtained in a 38 year old man with congenital heart disease. RV = right ventricle.

formed with an Advanced Technology Laboratory Ultramark 8 echocardiograph equipped with a dynamically focused 3.5 and 5.0 MHz annular array transducer, digital image processing, frame grabber and cine loop review. Routine echocardiographic views were altered so that each vessel could be imaged parallel to its long axis. The most useful techniques for recording images of each coronary artery are described as follows:

Left main coronary artery. This artery was imaged from a parasternal short-axis view at the level of the aortic root with the transducer in the third or fourth left intercostal space, with 30° clockwise rotation, or apically from a five chamber view with cranial angulation of the transducer. These views have been previously described by several investigators (1–6).

Left anterior descending coronary artery. The left anterior descending coronary artery was imaged from a modified left parasternal long-axis view generally using the third intercostal space. The transducer was angled 10 to 30° superiorly and laterally toward the pulmonary artery and then rotated approximately 10° clockwise.

Left circumflex artery. The left circumflex coronary artery was imaged parasternally in the third or fourth left intercostal space or from an apical five chamber view. From the parasternal short-axis view of the aortic valve, the

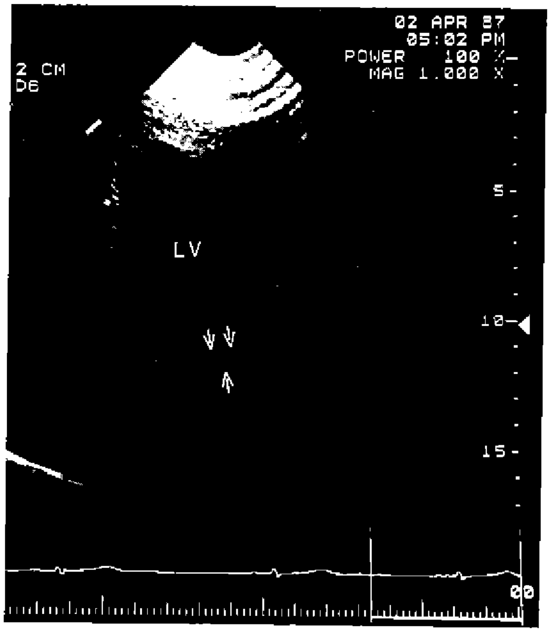


Figure 3. The proximal left circumflex coronary artery (arrows) is shown using a modified apical four chamber view in a 30 year old normal man. LV = left ventricle.

transducer was rotated approximately 10° counterclockwise and angled slightly superiorly. From the apical four chamber view, the transducer was rotated slightly clockwise to move the imaging plane posteriorly and inferiorly to include the left atrioventricular groove.

Right coronary artery. The ostium of the right coronary artery was imaged from both the parasternal short-axis and subcostal views. The proximal and mid right coronary artery was imaged from the parasternal short-axis view at the level of the aortic valve by sliding the transducer away from the sternum and angling it superiorly and rotating clockwise. From the short-axis subcostal position, the transducer was angled toward the pulmonary outflow tract. The mid and distal right coronary artery was imaged from the apical four chamber view. The transducer was angled slightly posteriorly and rotated approximately 10° clockwise.

Image analysis. Real time images were stored in cine loop, permitting frame by frame review; optimal delineation was usually obtained in late diastole. Imaging and recording time averaged 10 to 20 min per patient. Stop frame images were analyzed by two independent observers who were unaware of other patient data. The length and luminal diameter of each coronary artery segment visualized was digitized manually. For this purpose, the left anterior descending artery was arbitrarily divided into proximal (first 5 cm) and mid (5 to 10 cm) portions, and the right coronary artery into proximal (first 5 cm), distal (beyond the acute margin) and mid (between proximal and distal) portions.

Results

High quality images of portions of each of the four epicardial coronary vessels adequate for assessment of luminal diameter were obtained in all subjects. The left main coronary artery was seen in 30 (86%) of the 35 subjects and its bifurcation in 15 (Fig. 1A). The left anterior descending coronary artery was seen in 30 subjects (Fig. 1B and C and Fig. 2) (mean length 3.9 ± 2.3 cm, maximal length 7.5), the left circumflex artery in 11 (1.1 ± 1.0 cm, maximal 3.0) (Fig. 3), and the right coronary artery in 32 (mean 5.6 ± 2.6 cm, maximal 12) (Fig. 4). Table 1 shows the average length visualized and luminal diameter of segmental portions of the left anterior descending, left circumflex and right coronary arteries. Septal or diagonal branches were seen in 11 (31%) of the 35 subjects, a marginal branch in 1, the coronary sinus in all and smaller veins in 3.

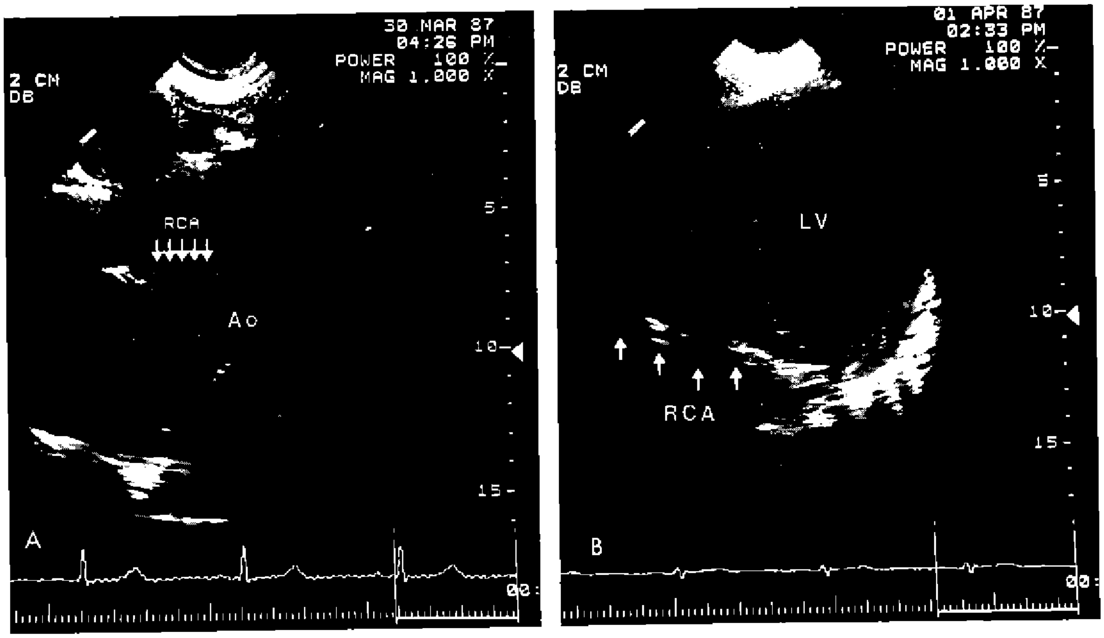
Coronary artery disease. Of the five patients with coronary artery disease, catheterization-documented lesions were correctly identified in four (two in the left anterior descending, one in the left main and one in the right coronary artery) (Fig. 5). In the fifth patient, the proximal coronary arteries were obscured by calcifications in the aortic valve. Calcification of the coronary artery lesions, however, did not limit resolution of the artery.

Discussion

Problem in echocardiographic imaging of the coronary arteries. This study demonstrates that high quality images of both proximal and distal coronary arteries and measurement of luminal diameter may be obtained noninvasively using cross-sectional echocardiography. Satisfactory examinations of part of the left main, left anterior descending, and right coronary arteries were obtained in 86 to 91% of patients; the circumflex artery was seen in only one third.

In previous reports (1–6), successful visualization of the left main coronary artery was achieved in 58 to 99% of patients. Imaging of just the origins of the left anterior descending and circumflex arteries has been more difficult, being reported in 53 and 34% of patients, respectively (3,4). Few data are available regarding visualization of the right coronary artery.

Some of the difficulties encountered in obtaining adequate coronary artery images are those inherent in any echocardiographic study and include obesity, unfavorable chest wall configuration, chronic obstructive lung disease and advancing age. These problems are augmented by several features unique to coronary artery imaging. The small diameter of the coronary arteries approaches the beam width of conventional equipment. This is especially true when using apical views because the coronary arteries are relatively distant from the transducer, and beam width increases with depth.



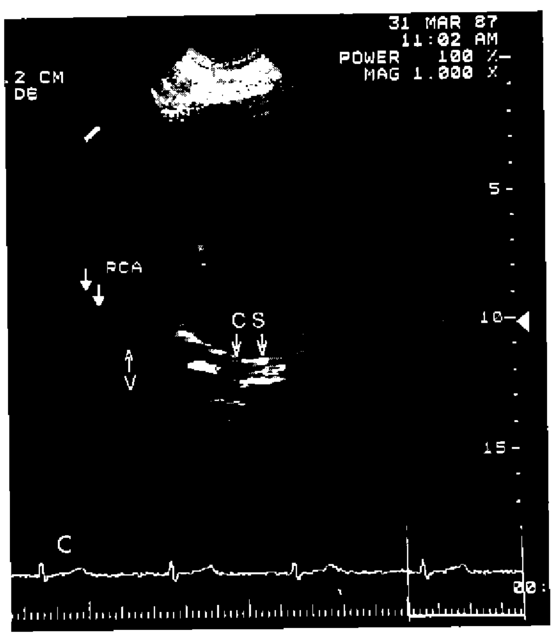


Figure 4. Three images of the right coronary artery (RCA). **A,** The origin of the right coronary artery is shown using a subcostal view in a 76 year old normal woman. **B,** The mid and distal right coronary artery are visualized using a modified apical four chamber view in a 34 year old man with aortic regurgitation. **C,** The right coronary artery and adjacent vein (V) are displayed using a modified apical four chamber view in a 37 year old normal man. The vein is seen draining into the coronary sinus (CS). Ao = aortic root; LV = left ventricle.

Further, such views require high penetration to yield adequate resolution.

Because echocardiographic imaging is tomographic by nature and epicardial vessels follow the curving surface of the heart, description of a long portion of a single vessel can only be accomplished through use of multiple views, each with a slightly different transducer angulation, each displaying a different but adjacent segment of the artery (Fig. 1 and 2C and D). Further, the vessels move continuously in and out of the imaging plane in concert with normal cardiac motion, and may only be visible briefly during the cardiac cycle.

Imaging of coronary artery disease. The difficulties are especially important in the diagnosis of coronary artery disease. Positive identification of significant luminal narrowing requires visualization of the normal artery both proximal and distal to a suspected lesion. An apparent obstruction may simply be due to motion artifact or to curving of the vessel out of the imaging plane. As an alternative, high intensity coronary artery echoes have been proposed as a finding diagnostic of coronary atherosclerosis. Acknowledged limitations of this technique include a requirement for modified gray scale processing (14,15), possible overreading of a left anterior descending artery plaque as left main

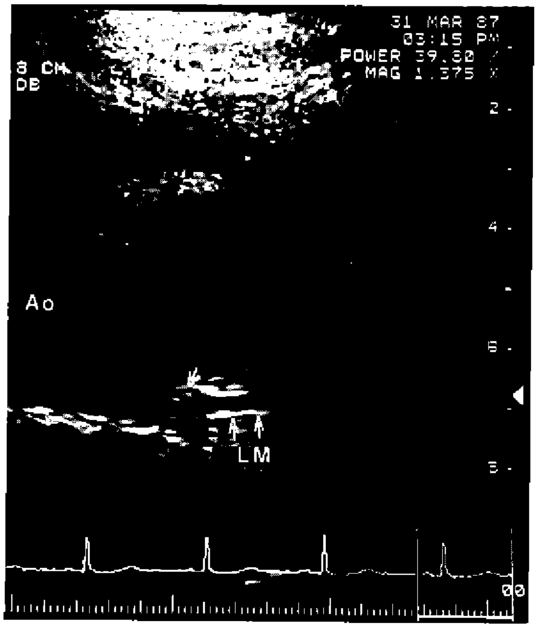


Figure 5. The left main (LM) coronary artery **(double arrows)** is imaged from a modified parasternal short-axis view. At its origin from the aorta (Ao), intraluminal echoes **(single arrow)** suggest an ostial lesion, which was confirmed by coronary angiography in this 65 year old woman. The increased echoes are especially obvious when compared with the clear, echo-free left main coronary artery seen in Figure 1A.

coronary artery disease and confusion of epicardial fat (2) or cholesterol crystals (16) with calcium.

Advantages of present method. Because of the limitations of previously available scanning equipment, development of techniques for transducer placement and angulation to obtain views of vessels other than the left main coronary artery has not been necessary. Our results demonstrate that modifications of standard apical, parasternal and subcostal echocardiographic views can yield images of substantial portions of the epicardial coronary vasculature. The more extensive visualization of coronary anatomy is a necessary prerequisite to any possible clinical application of coronary imaging, including positive identification of coronary lesions. Our success is related in part to the use of all acoustic windows, allowing visualization in a greater percentage of patients. More important, several features of the echocardiographic equipment minimize difficulties previously inherent in coronary imaging. The annular array transducer used in the present study provides high penetration without loss of resolution, enabling production of clearer images of smaller, deeper structures. Its technology incorporates both horizontal and vertical focusing of digitally encoded images, providing multiple depth focusing of thinner (approximately 1 mm) tomographic slices. The cine loop allows capture, frame by frame review and recording and repeated playback of a single cardiac cycle during which the coronary vessel may be visible only briefly.

Table 1. Average Segment Length and Luminal Diameter of the Three Coronary Arteries

	LAD			RCA		
	Prox	Mid	LCx	Prox	Mid	Distal
n	23	11	11	17	24	18
Length (cm)	4.2	1.9	1.1	2.7	3.6	2.9
Lumen (mm)	4.9	4.6	3.8	3.1	3.1	2.7

LAD = left anterior descending coronary artery; LCx = left circumflex coronary artery; Mid = middle segment; Prox = proximal segment; RCA = right coronary artery.

Limitations of method. Our study has some important limitations. Although we successfully obtained coronary images in all subjects, views were sometimes limited and complete examination of the entire epicardial vasculature was not possible. Because only segments of the vessels can be visible in any single view, assessment of long sections of an artery requires piecing together successive views of adjacent segments. Even in the "best case," circumflex artery imaging was suboptimal. Coronary imaging will always be affected by patient factors known to influence overall routine echocardiographic image quality; in addition, highly echogenic structures in the aortic root (such as a prosthesis or calcified valve) can limit resolution of the coronary ostia. Although we have demonstrated the feasibility of the technique in the elderly and in those with heart disease, its sensitivity, specificity and predictive value for recognition of coronary atherosclerosis remain to be defined. For example, although we were able to identify intraluminal echoes in some patients, images remain somewhat indistinct and are not yet of sufficient quality to permit quantitative evaluation of the severity of coronary stenoses. Our results need to be confirmed by others and by prospective studies evaluating the clinical utility of the methods presented.

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